

**343**

**RECOMMENDATIONS FOR CONDITION MONITORING  
and  
CONDITION ASSESSMENT FACILITIES FOR TRANSFORMERS**

**Working Group  
A2.27**

**April 2008**



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# Recommendations for Condition Monitoring and Condition Assessment Facilities for Transformers

## WG A2.27

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**ISBN: 978- 2- 85873- 031- 5**

## Foreword

During the A2 SC meeting on 4<sup>th</sup> June 2003 in Merida a task force TF A2.27 was set up to consider the merits of looking at standardising the interface between transformers and monitoring systems. This task force reported to the meeting in Paris on 3<sup>rd</sup> September 2004 that some progress had been made towards the objectives and sufficient interest had been shown to extend the work. A new working group was therefore proposed to CIGRE and was approved on 19<sup>th</sup> January 2005 becoming WG A2.27.

The WG was tasked with proposing and considering the benefits of possible standardisation of the interface between monitoring systems and the transformer. The interface may be the electrical or other connection to permanently installed sensors, the mechanical facility for the later fitting of sensors or the provision of relevant data from another collection system. The review to include, but not necessarily be limited to: tank valves, oil pipes, dielectric windows, bushing tap arrangements for fitting PD sensors, aerials, acoustic sensors, temperature, pressure and vibration measurement. In addition transformer design features that make condition monitoring or diagnostic testing easier or more accurate to be considered and recommendations developed where appropriate. The WG was asked to review where appropriate, the circumstances under which systems are installed, the methods of installation and whether there are safety concerns during or after installation without duplicating other work. Communication protocols were not be considered, but the WG output may help to guide transformer data requirements for example for IEC 61850 application.

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## **1 Introduction**

Over the past few years many transformer monitoring techniques and systems have been developed offering a variety of advantages for the transformer operator and asset manager. These advantages range from the ability to know the overload capability of the transformer to detailed monitoring of faults in the active part and accessories such as bushings and tap-changers. The cost and complexity of monitoring systems varies widely and the application of all the available techniques to all transformers from new is not financially justified. Instead a mix and match approach is more likely to be appropriate with the customer able to choose which type of monitoring is most appropriate, depending on the importance and health of the transformer. For example it may be decided that monitoring cooler operation is important from new, but monitoring partial discharge is only worthwhile when a problem has been detected by using routine dissolved gas analysis.

To facilitate this flexibility of approach to fitting condition monitoring, it is recommended by the working group, that there are certain sensors and facilities that should be provided on a new transformer. Providing these facilities and sensors will increase the ease and safety of fitting condition monitoring systems at any point in the transformer's lifetime and should help to lower the barriers to effective and economic use of these systems.

This document therefore sets out, in what is intended to be sufficient detail to form the basis of a specification, which sensors and facilities are necessary or desirable to have on a transformer to allow most if not all condition monitoring systems to be applied.

There is an increasing capability within substation control and data systems to directly collect data relevant to transformer condition without the need for specific condition monitoring hardware. This can potentially provide a path to implementing basic condition monitoring functions, but the relevant data must be available from the appropriate sensors. The WG has made some recommendations for sensors to provide this data.

The effective installation of a monitoring system also requires in many cases that a suitable communication link is provided for alarms to be transmitted to the system operator or maintenance organisation. Where this is done via a substation control system it is recommended that suitable provision is made for the communication of monitoring information even if a monitoring system is not fitted initially. Recommendations for the required alarm inputs are included in this document.

## **2 Scope and aim of the working group**

The group was originally set up as a task force following a discussion at the A2 colloquium in 2003, and was confirmed as a working group following the Paris meeting in 2004. The scope and aim were as follows:

The WG will propose and consider the benefits of possible standardisation of the interface between monitoring systems and the transformer. The interface may be the electrical or other connection to permanently installed sensors, the mechanical facility for the later fitting of sensors or the provision of relevant data from another collection system. The review will include, but will not necessarily be limited to: tank valves, oil pipes, dielectric windows, bushing tap arrangements for fitting PD sensors, aerials, acoustic sensors, temperature, pressure and vibration measurement. In addition transformer design features that make condition monitoring or diagnostic testing easier or more accurate will be considered and recommendations developed where appropriate.

Specifically the WG will:

- Review existing and developing condition monitoring systems and practices to determine the range of sensors and facilities employed.
- Determine whether standardization could improve the market for, or implementation of, condition monitoring systems, sensors or techniques.
- Make recommendations for the provision of sensors facilities or data from new transformers to facilitate the later application of condition monitoring or condition assessment.

Where appropriate the WG will review the circumstances under which systems are installed, the methods of installation and whether there are safety concerns during or after installation, but work already carried out in other forums specifically within the IEEE will not be duplicated. Communication protocols will not be considered, but the WG output may help to guide transformer data requirements for example for IEC 61850 application.

### **3 Review of existing and developing systems**

A review of the commercially available condition monitoring systems was carried out by the circulation of a questionnaire via the working group members to vendors. Many of the vendors were represented directly on the working group. In addition the needs of, and possibilities for, systems in the development stage were evaluated by the working group members, a number of whom have a direct involvement in the relevant technologies.

The review covered the types, number and location of sensors together with the acceptable interface between the sensor and the monitoring system, for example four wire PT100 or 4-20mA.

### **4 General**

For each sensor or data type consideration has been given to the most appropriate and cost effective interface to a monitoring system. This is based on the cost and complexity of the sensor and the number and type of monitoring systems that can use the information that the sensor or data source can provide.

### **5 Market situation for condition monitoring systems**

It was generally accepted by both users and manufacturers that the state of the market for condition monitoring systems is such that standardisation of the facilities provided on a new transformer for the later fitting of a condition monitoring system would have practical and economic benefits.

## **6 Types of condition monitoring systems**

There are several ways of implementing a condition monitoring system, for example:

- a) A stand-alone system local to the transformer most commonly using a PC or micro controller to collect and analyse or store the data usually with a communications link to a remote point for interrogation.
- b) A system using data acquisition units at the transformer collecting and transmitting data for analysis to a centralised PC based system within the substation. A communications link to a remote point for interrogation is usually incorporated.
- c) A system using the substation control system SCADA to collect and store the data for analysis at a remote location.

The recommendations in this document are not intended to favour any one of these types of monitoring architectures, rather to facilitate the use of all of them as appropriate to the type and extent of the monitoring required. For example data of high bandwidth from a PD sensor which requires a sophisticated local measurement and processing system may favour a monitoring system of type a) whereas a system such as one for thermal monitoring requiring slowly changing inputs from many standard sensors may favour approaches b) or c).

## **7 Review of sensors, data and recommendations for condition monitoring**

### **7.1 Temperature measurement**

Temperatures are used by the majority of monitoring systems to indicate the instantaneous thermal rating of the transformer and to infer the health of cooling systems and tap-changers.

Three alternatives for the interface are available and the desired one should be specified. It is recommended that a thermometer pocket is always provided even if any supplied temperature sensor is not installed in a pocket.

- Thermometer pocket to EN 50216-4
- PT100 four-wire sensor
- 4-20mA current loop output.

For the 4-20mA current loop it is recommended that a temperature range for oil temperature measurements of -40 to 120 °C is used, but different ranges may be needed particularly for use with high temperature insulating fluids.

Care should be taken that oil temperature measurements are not unduly affected by local tank heating effects such as from eddy currents or by local ambient conditions. It should be noted that the temperature measured by a sensor in a thermometer pocket may be several kelvin below the actual oil temperature.

It is recommended that the following temperatures should be available.

#### **7.1.1 Top oil**

This temperature measurement point should be representative of the temperature of the oil at the top of the tank. The measurement position should be the same as, or as close as possible to, the one used to measure the top oil temperature during the factory temperature rise test.

### **7.1.2 Bottom oil**

This temperature should be as representative as possible of the oil entering the bottom of the windings. For transformers with oil directed cooling this will normally be the oil temperature at the cooler outlet close to the transformer tank.

### **7.1.3 Cooler inlet oil**

This measurement should be taken from the cooler inlet oil and may be used to monitor cooler efficiency, but in some transformer designs there may be no practical difference between this measurement and the top oil measurement (see section 7.1.1) in which case the top oil measurement should be used.

### **7.1.4 Cooler outlet oil**

This measurement should be taken from the cooler outlet oil and can be used to monitor cooler efficiency. In some transformer designs there may be no practical difference between this measurement and the bottom oil measurement (see section 7.1.2) in which case only the bottom oil temperature should be used.

### **7.1.5 Cooling medium at inlet to coolers**

This measurement should be representative of the temperature of the cooling medium (normally air or water) at the inlet to the coolers. In the case of an air temperature measurement, the sensor should be mounted in the shade. An air temperature sensor would not normally form part of the transformer and it is generally easy to fit retrospectively. If lower accuracy can be tolerated the ambient temperature may be taken from a substation sensor. If water is the cooling medium, then a sensor or thermometer pocket should be included at both the cooler inlet and outlet.

### **7.1.6 Tap-changer diverter switch compartment(s) oil**

This measurement is used to detect abnormal heating in the diverter either due to a fault or an unusually high number of tap-changing operations in a short time. The measurement should be made at the top of the compartment. The sensitivity of the monitoring based on this measurement is improved if the temperature of the oil adjacent to the diverter switch compartment is also measured, whether this is the top oil temperature of the transformer main tank or the selector compartment oil temperature.

### **7.1.7 Tap-changer selector compartment(s) oil**

This measurement is only required for transformer with a separate oil compartment for the selector. The measurement should be made adjacent to the diverter.

### **7.1.8 Main tank adjacent to tap-changer (for transformers with bolt-on type tap-changers)**

Where the main tank top oil measurement is not representative of the temperature of the oil next to the tap-changer an additional temperature measurement may be required to allow a more accurate differential temperature measurement to be used to detect thermal faults in the tap-changer.

Note: for transformers with a selector switch type tap-changer a similar arrangement to that for the diverter switch described above should be used.

## **7.2 Winding hotspot temperature**

Where a winding temperature indicator is provided it is recommended that the output representing the winding hotspot temperature in the range 30-150 °C is made available as a 4-20mA signal. This indication is useful for the system operator and is not necessarily used by monitoring systems. Generally a winding temperature indication is required for each winding if a tap-changer is fitted or the transformer has more than two windings.

The winding hotspot temperature may be derived by a monitoring system using the oil temperature and load data.

It is possible to make direct measurements of the winding hotspot temperature using a fibre optic technique. If such a system is fitted the hotspot temperature should be made available as a 4-20mA signal.

Although direct measurement provides useful additional information, the sensors cannot be fitted after the transformer is installed, the additional information gained may not be sufficient to justify the additional cost and complexity of fitting the sensor to all new transformers. Application may therefore be limited to the most critical transformers. Direct hotspot measurement is valuable for determining the thermal parameters of a transformer, see IEC 60076-7.

### **7.3 Load and short circuit current**

The load current is used in conjunction with oil temperatures to deduce winding and hotspot temperatures and time to over-temperature. Load current is also needed for tap-changer contact wear calculations, over-current blocking of tap-changer operation and cooler efficiency monitoring. It is recommended that this information is made available to the monitoring system via a data link to the substation control system, but failing this, it can be derived from a transducer on the secondary connection to an existing primary current measuring CT. On new transformers a CT to measure load current is required, this may be the CT used to drive the winding temperature indication. Where the transformer has more than two windings, a load measurement is required on each winding.

If fault recorders are not already installed then an additional current measurement on each line terminal capable of measurement up to the short circuit current level should be made available to the monitoring system.

If CTs are to be specified for monitoring on a new transformer, they should have a measuring range to accommodate the short circuit current with a burden of 2VA (plus the load of the wiring between the transformer and the monitoring system). The accuracy should be better than 5% with an output of 1A at rated current.

### **7.4 System voltage**

The primary system voltage is used by some monitoring systems and may be used for automatic tap-change control. The signal is normally provided as a voltage from a separate voltage transformer that is not part of the power transformer. This information may also be made available via a data link from the substation control system. Voltage measurements can also be made by the monitoring system using a signal derived from a bushing tap, see also section 7.10.

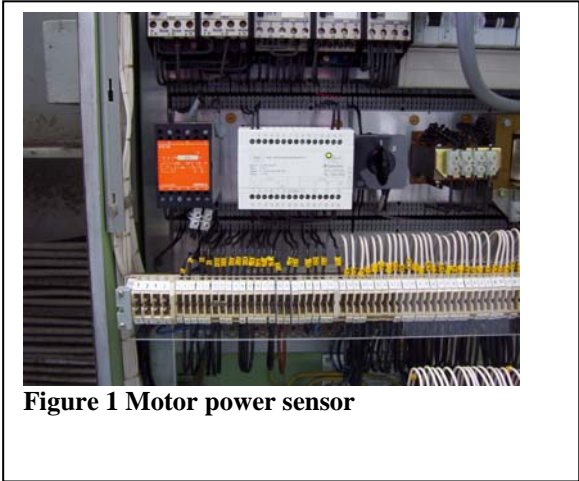
### **7.5 Tap-position**

Knowledge of the tap-position is important to enable a number of monitoring functions. It is recommended that a connection is made available in the tap-changer motor drive cubicle. For monitoring on new transformers, a binary coded decimal (BCD) switch is recommended, but other outputs may be required to interface to existing monitoring systems. The information may also be made available via a data link from the substation control system.

### **7.6 Tap-changer motor drive and other sensors**

#### **7.6.1 Motor real power/torque**

The real (active) power consumption of the tap-changer motor drive can provide useful monitoring information, in particular the torque of the motor. It is recommended that space is provided to fit a real power transducer in the motor drive cubicle. It is not sufficient to measure only the motor current, because this value does not correlate directly with motor torque which is the critical value for mechanical monitoring of the tap-changer mechanism. Direct measurement of the motor torque using a torque sensor can be used as an alternative.



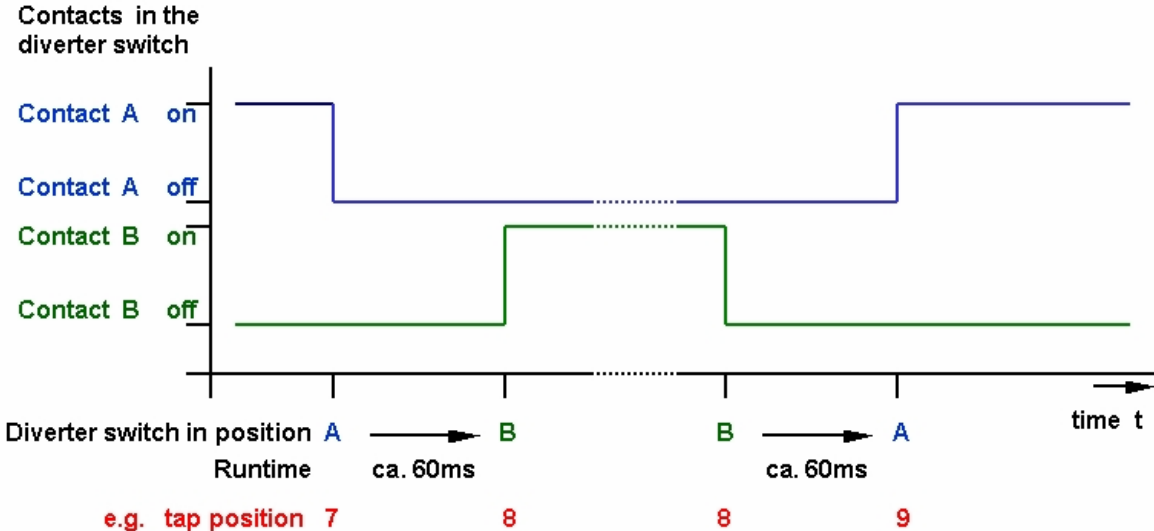
**Figure 1 Motor power sensor**

**7.6.2 Selector angular position**

The angular position of the selector can be derived from the motor run time, but it is recommended that a mechanical angle position resolver with a sine/cosine output to indicate the angular position of the motor drive output or the selector position is provided on new tap-changers to improve the accuracy of this measurement.

**7.6.3 Diverter position switches**

It is recommended that for new transformers, two switches are provided which may be driven directly or indirectly to indicate that the end position of the diverter switch travel has been reached. The operation time of the diverter can be deduced from this information. The switches should operate according to the following diagram.



For some designs of tap-changer where the fitting of such switches is difficult or could lead to reduced reliability then alternative methods of deriving the diverter position may be used.

Diverter position switches are particularly useful where separate tap-changers are used for each phase for example in phase shifters or line-end applications where they can be used to detect failures that result in an out-of-step condition. This condition can cause very high circulating currents. Alternative methods for detecting this condition are possible.

## **7.7 Oil levels**

Oil level monitoring of all separate oil filled compartments is a useful means of detecting leaks and consequential environmental threats. Oil level monitoring can also help to prevent unexpected buchholz operation due to low oil. It is recommended that a 4-20mA output sensor is provided to indicate oil level over the normal operational range.

## **7.8 Facilities for condition monitoring of the transformer and oil using oil analysis.**

There are a range of sensors available that require access to the transformer oil in order to give information on the condition of the transformer and the oil.

Measuring dissolved gas-in-oil is a well established way of detecting faults in the transformer. The devices available fall into two categories:

**Single output systems**, that provide a single output signal that is in some way proportional to one or several of the gasses present. These systems are useful for detecting problems and correlating gas production with particular operating conditions, giving clues as to the origin of the fault.

**Multiple gas analysers**, that provide information on the level of several diagnostic gasses. These systems are particularly useful for helping to determine the type of fault and its development.

The available dissolved gas-in-oil sensors have one of two types of fitting:

**Direct, mounted** on a valve on the side of the tank or in a pipe with direct access to the oil. Single output systems may be of this type.

**Oil sample loop**, where the instrument continuously or periodically takes an oil sample via small bore pipework, returning the oil to the same or a different point. Generally multiple gas analysers are of this type.

Generally dissolved gas-in-oil sensors are expensive, particularly multiple gas analysers, and require maintenance or replacement within the transformer lifetime. Therefore it is recommended that fittings are provided on the transformer to allow easy installation of this equipment when required. Installation is most likely to be required when routine dissolved gas analysis of a sample analysed in a laboratory shows a positive result.

The monitoring of moisture in oil with a correlation to loading and temperature can give useful indications of the overall moisture status of the transformer. Transformers may be expected to be dry when new and so a moisture sensor is more likely to be justified on older units. Moisture sensors generally require a direct type of fitting.

Additional sensors for determining oil properties such as dielectric strength and dielectric loss are available. These can also use a direct type fitting. There is a significant amount of research and development continuing on sensors that conduct oil analysis or measure oil properties, and it is very likely that new sensors will be developed. It is expected that new sensors will continue to be either direct mounted or using an oil sample loop.

It is recommended that fittings provided should comprise:

#### **7.8.1 Facility for fitting direct gas in oil sensors in the oil flow**

A DN50 valve should be provided on the cooler circuit outlet side of the cooling pump (if any) or at a point on the tank where the oil is moving and will provide a representative sample. The access to the oil should be horizontal and short (approximately 100mm). There must be a sufficient free area, preferably 500mm outside the valve for the sensor fitting.

#### **7.8.2 Additional direct oil sensor fitting**

An additional DN50 valve may be fitted in a similar way to the valve in section 7.8.1 for a moisture or other sensor.

#### **7.8.3 Facility for fitting systems requiring an oil sample loop**

A DN15 valve should be provided to allow the continuous extraction of a representative sample of the oil for analysis by a monitoring system. A facility should be provided to return the oil preferably to the conservator or a position above the buchholz relay. This facility can be combined with the normal oil sampling valve.

### **7.9 Diverter oil condition**

A fitting, such as a blanking plate over a hole with a minimum diameter of 25mm, allowing access to the oil in the diverter switch is recommended for future monitoring of diverter oil condition. Monitoring diverter oil condition, either dielectric strength or moisture may be useful for line-end tap-changers subject to condition based maintenance.

## 7.10 Bushing tap voltage/current

Partial discharge (PD), winding frequency response, fast transient monitoring and bushing monitoring can all be done with a high bandwidth connection to a bushing tap. To make this connection efficiently it is recommended that all new condenser type transformer bushings should be provided with a test tap connector. Preferably this should be designed according to ANSI C57.19.01. This connection can also be used to monitor system voltage. Precautions must be taken with connections to the bushing tap to prevent damaging voltages appearing on the tap under both working and impulse conditions.



**Figure 2 Example of a bushing tap voltage sensor**

## 7.11 Partial discharge detection and location inside the tank

Partial discharge (PD) detection and location can be performed using radio frequency [1,2] and acoustic [3,4] techniques. These techniques involve the detection of electromagnetic or acoustic signals radiated by the PD.

Ultra high frequency (UHF) PD location techniques require that the sensor is introduced into the tank through a valve, or mounted on a dielectric window or permanently installed inside the tank.

Acoustic sensors for PD monitoring can be fitted by means of magnetic or suction clamps, or adhesive as required to the outside of the tank and in this case no special facilities are required. Acoustic sensors can also be introduced into the tank through a valve, with the potential for improved performance.

Since PD detection and location techniques are still evolving it is recommended that DN50 valves are provided for the later fitting of probes as this provides the greatest flexibility for the future. Alternatively dielectric windows can be provided for UHF sensors. Typically this would consist of an aperture of at least 120mm diameter in the tank covered by a 20-30mm thick plate, made of nylon 6-6 or PTFE. Further details of dielectric windows are provided in references [5] and [6]. It is not recommended that windows are fitted without specific knowledge of the available sensors and techniques.

For PD location purposes, a total of four sensor locations are required, ideally each near a different corner of the tank and not all in the same plane. Valves for PD sensors must be located in position where a metallic protrusion of 50mm into the tank is permissible (a low power frequency electric field area). Additionally the area inside the tank 0.25m around the valve should be free of any

obstructions such as frames, tank wall shunts or the corner of the tank. For PD detection only, one or two valves are required and these may be the same valves as used for oil filtering provided the above requirements regarding position are met.

Knowledge of the position of the windings, core, connections, leads and obstructions within the tank is very helpful for the interpretation of partial discharge location information. Consideration should be given to how this information can be made available over the lifetime of the transformer.



### **7.12 Capacitive couplers**

The provision for fitting capacitive couplers may be provided close to each line terminal. These couplers are principally for the measurement of very fast transients. Either a capacitive transducer is fitted or a removable plate (hand-hole cover) for later fitting is provided. This is a very specialised sensor only applicable to particular installations and it is not recommended for general application.

### **7.13 DC neutral current**

In high latitudes geomagnetic (quasi DC) currents may flow in the transformer neutral. Monitoring these currents can give indications as to the cause of diagnostic gasses or other fault conditions. It is recommended that a 0.5m length of conductor with a clearance to the tank of 0.3m is provided in the transformer neutral connection accessible at ground level to allow the fitting of a hall effect or other suitable transducer for monitoring these currents in transformers that might be affected.

### **7.14 Cooler operation**

For monitoring the operation of the cooler it is recommended that each pump and fan contactor is provided with an auxiliary contact. Flow gauges or switches particularly for directed oil cooled transformers are recommended to monitor the pump operation. Motor current measurements can be used to detect fan or pump problems but multiple measurements for example of each fan are not recommended.

### **7.15 Magnetic circuit**

Monitoring of the current in the core earth can indicate faults or circulating currents. It is recommended that the core and frame earth connections are brought out through bushings and earthed externally so that the current can be measured by means of a CT. These connections can also be used for PD monitoring especially for core to tank problems.

## 7.16 Bushing oil pressure

Pressure measurements can be useful for monitoring fault conditions and oil leaks on sealed systems such as bushings. It is recommended that either a pressure sensor with a 4-20mA output or a facility for fitting a sensor is provided on large oil filled bushings.



**Figure 4 Bushing pressure sensor**

## 7.17 Buchholz gas volume

Monitoring the rate of production of fault gas within a transformer can provide useful information about the development of a fault. The facility required for fitting a gas volume sensor is usually already provided by the gas release petcock on the buchholz relay. The sensor itself would only be fitted once the transformer is known to have a gassing fault. The safety of continuing to use a transformer with a gassing fault must be carefully evaluated.



**Figure 5 Buchholz gas volume sensor**

## **8 Summary of recommended condition monitoring facilities**

As set out in section 7, there are a large number of possible sensors available, which can be used by an on-line monitoring system. The set-up should be adjusted to the size, age, condition and importance of the transformer.

Table 1 summarises the recommendations for different levels of monitoring provision appropriate to general classes of transformers.

Level 1: The minimum set of sensors required to provide basic information about the transformer operation and the minimum facilities for further monitoring should a fault develop.

Level 2: The set of sensors and facilities that provide a good level of information on transformer condition, this would be appropriate for large and important transformers. In general where it is recommended that a sensor is fitted then it will be monitored using the substation SCADA system even if a monitoring system is not fitted.

Level 3: The set of sensors and facilities that are thought to be useful for condition monitoring, including those for specialised and critical applications. Including all these sensors and facilities on a particular transformer is unlikely to be economically justified. Where it is recommended to fit a sensor at level 3 that is only a facility at level 2 then this indicates that it is recommended that the sensor should form part of a monitoring system if this is provided from new.

**Table 1 Summary of recommended condition monitoring facilities**

	Sensor	Ref section	Level 1	Level 2	Level 3
Active Part	Top Oil Temperature	7.1.1	Fit	fit	fit
	Bottom oil temperature	7.1.2		facility	fit
	Gas-in-Oil Content (single output)	7.8.1	facility	facility	fit
	Moisture in Oil	7.8.1		facility	fit
	Oil Level in Conservator alarm	10.3		fit	fit
	Oil Level in Conservator indication	7.7		fit	fit
	Multiple gas monitor	7.8.3		facility	facility
	Partial discharge sensor	7.11		facility	facility
	DC Neutral current	7.13			facility
	Magnetic circuit	7.15		facility	facility
Cooling Unit	Cooling Medium Temperature	7.1.5		facility	fit
	Cooler operation	7.14		fit	fit
	Cooler Inlet oil Temperature	7.1.3			fit
	Cooler Outlet oil Temperature	7.1.4			fit
Bushing	Voltage at Bushing Tap	7.10	facility	facility	fit
	Load Current	7.3	fit	fit	fit
	oil pressure	7.16			fit
OLTC	Tap-Position	7.5	facility	fit	fit
	Active Power Consumption of Motor Drive	7.6.1		facility	fit
	Diverter switch compartment oil temperature	7.1.6		facility	fit
	Selector compartment oil temperature	7.1.7		facility	facility
	Main tank temperature near tap-changer	7.1.8			fit
	Diverter oil level indication	7.7			fit
	Diverter oil level alarm	10.3		fit	fit
	Diverter oil condition	7.9		facility	fit
Diverter switching supervision	7.6.3			facility	fit

## **9 Recommendations for condition assessment test facilities**

### **9.1 General**

There are some design features and facilities that can be provided and tests that can be performed on new transformers that make subsequent condition assessment testing (applied when the transformer is off-circuit), easier to apply and interpret. Common condition assessment techniques include the following:

- Dissolved Gas Analysis
- Winding Resistance
- Insulation Resistance
- Dielectric Response Measurements
- Frequency Response Analysis
- Capacitance and Tan delta measurements, active part
- Capacitance and Tan delta measurements, bushings
- Magnetisation current
- Turns ratio
- Short circuit impedance
- Internal inspection
- Tap-changer condition

The condition assessment techniques themselves have been described extensively elsewhere. The following recommendations are intended to point towards areas of the transformer specification that can be used to facilitate condition assessment testing.

### **9.2 External core earthing**

Bringing the core and frame earth connections out of the tank through bushings allows the integrity of the core to frame and frame to earth insulation to be checked without oil handling. Further information about the frame insulation can be obtained from outside the tank if the HV side frame is earthed separately from the LV side frame. The insulation level (safe applied voltage test level) should be clearly indicated in the transformer manual and on a label beside the core and frame earth terminals.

### **9.3 External earthing of stabilising and test windings**

Where a winding is provided for factory test purposes, it can be useful to provide an external earth connection so that the insulation of this winding can be checked on-site. Delta stabilising or tertiary windings should be earthed outside the tank because effective phase to phase comparisons of winding frequency response cannot be made with one corner of a delta winding earthed.

### **9.4 Oil sampling points**

For easy routine dissolved gas analysis and other oil tests suitable sampling points should be provided accessible from ground level whilst the transformer is in service, connected to the top and bottom of the main tank. Similarly a sampling point should be provided on each separate oil compartment containing electrical parts, for example tap-changer compartments and cable disconnecting chambers.

## **9.5 Separate neutrals for each phase**

For star connected windings it is possible to bring the neutral terminal of each phase out of the tank separately so that the star point can be opened for testing. This arrangement allows power factor and capacitance measurements to be made separately on each phase increasing the sensitivity of the test. It also allows a fault to be located to a particular phase. Electrical separation of the phases may be achieved by removing or disconnecting a neutral end diverter. The economic justification for providing separate neutrals needs to be considered and will depend on the voltage and current level at the neutral.

## **9.6 Separate compartment for tap-selector**

The oil surrounding the tap-selector can be kept separate from the oil in the main tank of the transformer by means of a suitable barrier board. This arrangement allows separate oil samples to be taken so that tap-changer and main tank faults can be distinguished. The lower oil volume in the selector compartment also makes dissolved gas analysis on this component more sensitive. The disadvantages of additional cost and complexity in the transformer design need to be carefully considered.

## **9.7 Busbar access and disconnection facilities**

### **9.7.1 Air insulated terminals**

Consideration at the substation design stage as to how the transformer terminals can be accessed for testing is necessary to make subsequent testing operations efficient and safe. In particular power factor and capacitance tests require an air or dry polyethylene-insulated break between the terminals and earth. FRA tests require a defined repeatable break in the connection between the transformer and the power system, preferably at the bushing terminal. Where high current connections typically for the LV of a generator transformer are enclosed in ducting, access for testing should be considered in the design.

### **9.7.2 Gas insulated terminals**

Direct connection of a transformer to a gas-insulated duct can make disconnection for testing difficult and expensive. A suitable method of making test connections, preferably without removing gas should be considered.

### **9.7.3 Direct cable connections**

Where a transformer is directly connected to a cable then consideration should be given as to how the transformer can be disconnected from the cable and connection made to the transformer terminals for testing. For connections made under oil, a disconnecting chamber that can be drained and refilled separately to the main transformer tank is often the most convenient solution.

## **9.8 Internal inspection**

Sufficient removable access panels should be provided to allow for the internal inspection of the active part of the transformer and the tap-changer. Inspection can be by means of CCTV or by direct entry to the tank. In the case of direct entry to the transformer tank the safety of such an operation needs to be carefully considered.

## **9.9 Benchmark tests**

There are a number of tests that can be performed on a new transformer to provide a benchmark or fingerprint for subsequent test results, improving the accuracy and reliability of interpretation. This applies in particular to the following tests and it is recommended that these tests are performed on each new transformer at the factory or during commissioning or both:

Frequency response analysis

Capacitance and tan delta between windings and to ground and where possible between phases

Capacitance and tan delta of each condenser bushing

Winding Resistance

Insulation Resistance

Dielectric Response Measurements

Magnetisation current

Turns ratio

Short circuit impedance

Tap-changer torque measurement

Measuring the torque versus selector angle characteristic of a tap-changer in the tap-changer factory can provide a useful benchmark for diagnosing problems, both after fitting in the transformer factory and in service.

## 10 Transformer generic model for substation control systems

A standardised interface in terms of the alarms, trips and indications expected from a transformer should make the specification and implementation of substation control systems and the commissioning of transformers simpler and easier. There is significant work being undertaken to develop generic models and nomenclature for the implementation of IEC 61850 compliant devices for substation use. The following is a suggested set of alarms, trips, controls and indications for transformers that has arisen out of the discussions held on condition monitoring systems within the working group.

### 10.1 Direct outputs

It is recommended that the substation control system is provided with appropriate inputs to receive signals from sensors on the transformer. These may be either directly useful to the system operator (indicated by \*) or can be used by a remote monitoring system to provide certain functionality such as continuous overload capability assessment.

Top oil temperature\*

Winding hotspot temperature (output from a winding temperature indicator or monitoring system)\*

Tap position\*

Conservator oil level\*

Moisture in oil

Dissolved gas in oil

Cooling medium temperature (could be substation ambient temperature)

Winding hotspot temperature (directly measured by a fibre optic sensor) (optional)

### 10.2 Monitoring system outputs

For the purpose of providing specific alarm indications to the system operator via the substation control system (SCS) it is recommended that the following digital inputs to the SCS are provided so that monitoring can be implemented without changes to the SCS.

Monitoring system health

Functional check of monitoring system health, one alarm per transformer, multiple monitoring system health alarms would be paralleled

Tap-changer blocked

The tap-changer monitoring system has acted to prevent further tap-changes

Tap-changer abnormal

The tap-changer monitoring system has detected a fault or requirement for maintenance in the tap-changer

Gas in oil abnormal

The gas-in-oil monitoring system has detected a change or abnormal situation

Cooling abnormal

Cooler monitoring has detected an abnormal condition with the cooling plant that may have reduced the thermal rating of the transformer

Bushing abnormal

The bushing monitoring system has detected an abnormal condition, eg. high or low pressure or change in capacitance.

Transformer abnormal

The transformer monitoring system has detected an abnormal condition not included in the other alarms, specifically problems with the partial discharge, moisture, oil levels

### 10.3 Normal transformer alarm and trip contacts

For completeness, the following list indicates the contacts commonly provided on a transformer which are not normally thought of as part of a condition monitoring system and so are not included in section 7, but still provide condition information. Generally these contacts are used to either trip protection or provide alarms to the system operator.

<b>Alarm or trip name</b>	<b>type</b>	<b>comment</b>
Main Tank Buchholz relay oil surge	trip	
Main Tank Buchholz relay gas collection	alarm	
Top oil temperature high	alarm	
Top oil temperature	trip	
Winding temperature high	alarm	
Winding temperature	trip	
Main conservator low oil level	alarm	
Main tank pressure relief device operated	alarm or trip	
Tap-changer diverter	trip	sudden pressure or oil surge
Tap-changer diverter pressure relief device operated	alarm or trip	
Tap-changer diverter conservator low oil	alarm	
Tap-changer motor tripped	alarm	
Cooler supply failed	alarm	
Tap-changer supply failed	alarm	
Breather failed	alarm	

## 11 Conclusions

The technology of sensors, systems and algorithms for transformer condition monitoring is developing rapidly, but many of the parameters and fitting facilities required for the systems and sensors can already be determined, and are less likely to change. It is the intention of the report to give recommendations that will enable transformer users, transformer manufacturers and monitoring system suppliers to develop a better understanding of what is necessary to prepare a new transformer to fit a monitoring system.

It is certain that different users, different circumstances of use and different sizes and types of transformer will mean that there can be no one type of monitoring system to suit all transformers. Indeed the need for and type of monitoring required is likely to change during the lifetime of a transformer. However it is expected by the working group that there is a basis for discussion that could lead to a useful degree of standardisation of the interface between the transformer and monitoring systems, enabling more economic and wider use of such systems in the appropriate circumstances.

The application of monitoring systems to transformers offers benefits particularly in detecting faults that can be fixed before causing irreparable damage, for example in tap-changers and coolers, or in diagnosing faults and determining if they can be repaired, lived with, or require transformer replacement. Monitoring of tap-changer function and transformer thermal performance is becoming a normal and effective technique employed on many transformers and developments in reliability and functionality are to be expected. Developments in on-line dissolved gas analysis and partial discharge detection and location techniques are particularly notable. It would seem to be the right time to make sure that new transformers are prepared for their application to aid cost-effective utilisation now and in the future.

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**ISBN: 978- 2- 85873- 031- 5**